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Study of the Effect of Cloud Inhomogeneity on the Earth Radiation Budget Experiment

submitted by

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This research has analyzed data from the Earth Radiation Budget Experiment to examine cloud–radiation interactions. Two different sets of studies were carried out: one dealt with cloud effects, especially those of marine stratocumulus, on tropical radiation budgets; the other dealt with the treatment of inhomogeneous cloud effects on global radiation data. The tropical study was completed during the grant period. Substantial progress was made on the inhomogeneous cloud study, but this remains an unsolved problem which will continue to be studied.

Tropical Radiation Budgets.

ERBE data between 30°N and 30°S were examined thoroughly, and the results reported by Chang (1990), Chang & Davies (1990), Oreopoulos (1992), Oreopoulos & Davies (1992a,b,c). A number of results related to top of the atmosphere radiation budgets and cloud effects were noted.

Regional, seasonal and diurnal variation was noted by Chang, the highlights of which were presented by Chang & Davies (1990). In addition to presenting results for top of the atmosphere radiation budget and cloud forcing components, this study discovered a 7 W m^{-2} bias in the ERBE S–4 product for clear sky longwave fluxes at nighttime. If not removed, this bias affects subsequent studies of cloud radiative forcing using the S–4 data.

The study by Oreopoulos discovered a very interesting statistical relationship between the albedo of marine stratocumulus and sea surface temperature. These results have been submitted for publication in the Journal of Climate (Oreopoulos & Davies, 1992c), the abstract of which follows:

> Five years of Earth Radiation Budget Experiment data from December, 1984 to November, 1989 are analyzed, together with sea surface temperatures and cloud cover from other sources, to examine the relationship between albedo and cloud cover of tropical marine stratocumulus on sea surface temperatures. The study focuses on two regions of persistent marine stratocumulus with high values of cloud radiative forcing—one off the west coast of Peru, the other off the west coast of Angola.
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> Negative correlation coefficients of –0.8 between albedo and sea surface temperature are found when analyzing the seasonal variation of the entire data set. The interannual variation and the spatial variation of individual months also yield negative correlation coefficients of different values. The correlation between cloud cover and sea surface temperature is found to be similar, but not as strong as the albedo correlation, suggesting some dependence of cloud thickness on sea surface temperature for these regions. The corresponding albedo sensitivity averages –0.018 K^{-1}, with higher values reaching –0.04 K^{-1} locally. These findings of a relationship between albedo and sea surface temperature appear valid only over a range of temperatures from about 19°C to 25°C for the regions analyzed.
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> These results imply a potential positive feedback to global warming by marine stratocumulus that ranges from an additional absorption per 1 K

rise in sea surface temperature of ≈ 0.14 W m^{-2}, if the results are only applicable to the two regions of this study, to ≈ 1 W m^{-2}, if extrapolated globally to all marine stratocumulus. While these values are uncertain to at least $\pm 50\%$, the sensitivity of albedo to sea surface temperature in the present climate may serve as a useful diagnostic tool in monitoring the performance of global climate models.

Statistical Studies of Cloud Inhomogeneity

The early work on the statistical properties of the ERBE-measured radiances by Wen (1987) and Payette (1990) were confirmed, and this led to an exhaustive study of spatial autocorrelation functions of the data and the angular dependence of these functions. S–8 data were used exclusively for this study, and statistically reliable results were obtained for all solar zenith angles. My earlier finding that the ERBE bidirectional models are not self-consistent, but yield planetary albedos that depend on view angle, prompted a search for an objective improvement to the bidirectional models, the first attempt of which is contained in Payette (1990).

We discovered that the high degree of spatial correlation of the ERBE data can distort the results for limited data sets, but since this effect can be objectively removed once the spatial autocorrelation functions are known, these must be obtained first. It was possible to obtain a generic form of these functions that was applicable globally. The longwave and shortwave functions showed differences that are consistent with radiative transfer theory and are due to the additional degrees of freedom associated with the scattering of shortwave radiation. The shortwave functions also showed a dependence on view angle, however, that led to further study.

Unlike the angular dependence of the albedo, the angular dependence of the autocorrelation functions does not appear to be associated with any modeling assumptions. There is an effect due to the pixel expansion with view angle that must be removed, and this is also true of the longwave functions, which show less angular dependence. A consistent approach was developed that removed the dependence of the autocorrelation functions on pixel expansion. Once this effect was removed, the longwave functions showed negligible angular dependence, whereas the shortwave autocorrelation functions still increased significantly with angle. This angular dependence was found to be scene dependent, and appears to be associated with multiple scattering in inhomogeneous clouds.

While a qualitative explanation of this behavior can be given based on three-dimensional radiative transfer through inhomogeneous clouds, quantitative inversion of the statistical information to produce global cloud inhomogeneity characteristics has proven to be non-trivial, and remains an ongoing effort.

A major finding, however, the implications of which are currently being evaluated, appears to be the inapplicability of the principle of reciprocity on a statistical basis to almost all cloudy scenes. This principle does, however, appear to be generally applicable to clear oceanic scenes. This finding is currently being written up for formal publication.

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